1.—Laterite and Materials of Similar Appearance in South-Western Australia

Presidential Address, 1954

By S. E. Terrill, B.Sc., A.R.A.C.I., F.G.S.

Delivered—19th July, 1954

Introduction

The publication in 1952 of two small books, namely, "Problems of Clay and Laterite Genesis" and "Laterite and Lateritic Soils" emphasises the differences of opinion concerning the nature of laterite. It is difficult, at times, when reading these two books, to realise that both are written about what is supposed to be the same thing, namely, Laterite.

Laterite and lateritic gravels are to be found advertised in the daily press "For sale" columns as "gravel, best conglomerate," and whatever various scientific workers may say laterite really is, all are agreed that it is not a conglomerate, that is, a rock made up of waterworn boulders or pebbles set in a matrix usually of sand—mixed with a little clay perhaps—and hardened to a firm, solid rock.

A term in common use is "ironstone" and for general comprehensive use for dark coloured more or less massive, vermicular or concretionary, strongly coherent forms this term is very suitable for field use whilst "ironstone gravel" can be well applied to the loose unconsolidated material. This is not a strictly correct use of the term "gravel" perhaps but is sufficiently descriptive of the dark, reddish brown to black rounded stones in a loamy sand or sandy loam matrix. There are other forms which are light in colour and obviously do not contain much iron for which the term "ironstone" is clearly unsuitable. These forms are generally light brown and have the appearance of consolidated gravel or of a rock which will readily yield gravel but it is still more or less coherent: to these forms, for want of a better name, the term "gravelstone" is applied by the speaker for a field use prior to a more detailed examination in the laboratory.

Such names, while not attractive perhaps, are nevertheless descriptive and do not suffer from any implication of origin. Nor do they serve to cloak—as does the term "laterite" as it is widely used—manifest differences in mineral constitution and of structures and textures.

There is still considerable confusion at the present time in the use of the term "laterite." It is necessary that there should be some sorting out of the different types of rock now commonly included in the term by many who have contact with these, and the development of new names for some of them.

Mineralogical science was to see an immense proliferation of terms during the 19th Century. A different name would be given to a mineral from a new locality because it differed in some physical aspect such as colour or form from a previously described mineral of essentially the same composition. That process has been reversed of late, following upon a better understanding of the essential characters of minerals which has followed upon the X-ray studies of the past 40 years or so. Mineralogical nomenclature is becoming simpler and many names are gradually falling into disuse.

It is interesting to trace the application of the term "laterite" from the time it was first used by Francis Buchanan, M.D., F.R.S. up to the present dilemma, and to try and see along what lines further progress can be made. Despite assertions from time to time by various authors that this or that particular interpretation is generally accepted, there is indeed no universal acceptance of any particular usage even to this day, nor has there been over the past 50 years or so.

Since there is considerable emphasis placed on Buchanan's usage by some, particularly by soil scientists in Australia and elsewhere, it is perhaps desirable to examine Buchanan's journal of his journeyings in Southern India. This excursion was performed under the orders of the then Governor-General of India, the Most Noble the Marquis of Wellesley, and occupied the closing months of the 18th Century and the beginning of the 19th Century. The book, in three volumes, recorded his observations concerning the manner in which the people lived: their customs, the economy, and the nature of the countryside and the rocks occurring therein. In this journal, Buchanan recorded the occurrence of a peculiar rock, new to him, to which he gave the English name of "laterite" or "brickstone" and for science, the latinised version "lateritis."

Some years ago the speaker had the good fortune to add to his personal library a sound copy of this journal, in its three volumes, and it is interesting to read the original entries of the author of the term. More particularly is this so when one considers the nature of opinions and statements attributed to Buchanan by various writers on the subject of laterite terminology.

As an example of the kind of thing that has happened, Johannes Walther formed the opinion that a red colour was the significant criterion for laterite. Following this idea, Hellmers believed that Buchanan considered the red colour to be essential and that the rock was formed as a result of volcanic action. Neither of these concepts has been found by the speaker among the nearly 20 entries concerning laterite, not all of which are referred to in the index.

Buchanan's first entry concerning this material was that of 9th December, 1800, when he was in the vicinity of Kunamkulam south-east of Calicut. "Cunnung colung curry Angady," as he called the place, in a "Nazareny or Christian" village which he visited. He recorded:

"An old church . . . . . is now unroofed; but the walls, although built of indurated clay only, continue very fresh and strong. The altar is arched over with the same materials . . . . ."

The first entry concerning the field occurrence was made three days later, when in the vicinity of Angadipuram, a few miles north of Kunamkulam.

"After crossing the river, I came to a country like that near the *Nazareny* town in the Cochin Raja's dominions, and consisting of narrow vallies surrounded by low bare hills. The soil, in many places of these hills, is very intractable, and consists of a kind of indurated clay, which, on exposure to the air, become as hard as a brick, and serves indeed all the purposes of stone."

For the 20th and 21st December, 1800, Buchanan made the following entries concerning the iron ore which was smelted for the manufacture of steel.

"In all the hills of the country the ore is found forming beds, veins, or detached masses, in the *stratum* of indurated clay that is to be afterwards described, and of which the greater part of the hills of Malabar consists. This ore is composed of clay, quartz in the form of sand and of the common black iron sand. This mixture forms small, angular nodules compacted together and very friable. It is dug out with a pickaxe and broken into powder with the same instrument. It is then washed in a wooden trough . . . . placed in the current of a rivulet; . . . . The powdered ore is placed at the upper end . . . and . . . a man continually stirs it about with his hand. The metallic sand remains . . . . the quartz is carried to the lower end and the clay is suspended in the water and washed entirely away."

Thus Buchanan recorded the primitive character of part of the steel industry of that time and place. Note that it is the iron ore, which occurs in the so-called indurated clay "forming beds, veins or detached masses" that is smelted for the iron content, not the laterite itself. In another part of India, Pendleton recently saw slag heaps which he believed to have signs of the smelting of laterite for iron. While this laterite may be what might be described more properly as lateritic iron ore, it is possible that it was the iron ore in the laterite that was smelted.

After describing the furnaces and the smelting process Buchanan went on to state, and here I quote in full an oft-quoted entry:

"What I have called indurated clay is not the mineral so-called by Mr. Kirwan, who has not described this of which I am now writing. It seems to be the *Argilla lapidea* of Wallerius I, 395, and is one of the most valuable materials for building. It is diffused in immense masses, without any appearance of stratification and is placed over the granite that forms the basis of *Malayala*. It is full of cavities and pores and contains a very large quantity of iron in the form of red and yellow ochres. In the mass while excluded from the air, it is so soft, that any iron instrument readily cuts it and is dug up in square masses with a pickaxe and immediately cut into the shape wanted with a trowel, or large knife. It very soon after becomes as hard as a brick and resists the air and water much better than any bricks that I have seen in India. I have never observed any animal or vegetable *exuvia* contained in it, but I have heard that such have been found immersed in its substance. As it is usually cut into the form of bricks for building, in several of the native dialects it is called the brickstone (Itica cullu). Where, however, by the washing away of the soil, part of it has been exposed to the air, it has hardened into a rock, its colour becomes black . . . The most proper English name would be *Laterite*, from *Lateritis*, the appellation that may be given to it in science."

It is interesting to find that the reference to "Mr. Kirwan" is almost certainly to R. Kirwan, who published several books on agricultural chemistry and allied subjects and in particular, in 1894, a book in which he described, among things, indurated clay, citing as the typical example the clays at Stourbridge, England, now considered to be kaolinic in character.

The reference to *Wallerius I, 395* is, with very little doubt, a reference to page 395 of Volume 1 of the 1778 Vienna Edition of Wallerius' "Systema Mineralogicum," a reference work on systematic mineralogy written in a form of Latin, then the universal language of learned men in all parts of Europe. I am indebted to Miss Ethel Curran for assistance in the translation of the relevant passages. Wallerius gave the Swedish, French and German names, all meaning hardened, lithified or indurated clay. It may perhaps be significant that the German name is given as "steinthon" and not "steinlehm," suggesting a hardened china clay or a clay with little colouring impurity.

All the forms described by Wallerius—who, incidently was Professor Royal of Chemistry, Metallurgy and Pharmacy in the University of Uppsala in the middle and late 18th Century—have the appearance of clay, mostly unstratified, are stoney-hard and entirely lack the unctuous feel of most clay: they cannot be softened with water: they are softer than steel but become so hard when burnt that they will strike sparks from steel.

The group in which Wallerius placed the *argilla lapidea* is one which also included soapstones, serpentines and potstones or altered talcose greenstones. It would seem that Buchanan considered the laterite to have some of the properties of the group, but here again, we cannot recognise all the properties as applying to any one form of laterite. These rocks are all of them light coloured, structureless for the most part, amorphous, soft enough for use as a substitute for chalk, can be scraped with a knife, do not throw sparks when struck with steel. When exposed to the air they become harder rather than undergo disintegration, but they do disintegrate in time, becoming more earthy in appearance like the yellowish or greyish clay seen in fissures of potstones or impure talcose greenstones. When dry they absorb water but are not softened by it. When calcined they become so hard as to strike sparks with steel and burn to light yellow or grey colours. Fused with various salts they yield light or ash coloured strong masses or glasses. Mixed with clay the powders harden somewhat but with lime and gypsum they do not fuse unless siliceous material is added. These rocks do not effervesce with mineral acids but some does go into solution, more with hydrochloric acid than with nitric acid and with this more than sulphuric acid, as is shown by the amount of precipitate obtained with alkali carbonates. However, the amount that goes into solution seems to be proportional to the depth of colour of the stone. One of the several types of *argilla lapidea* is tawny to dark in colour.

I have given the properties of this rock at length, partly in order to indicate the scanty nature of the information there existed then concerning some rocks. Relatively simple tests and keen observation had to be relied upon, for this was in the days before microscopes of any kind were in common use, and 50 years or so before the petrological microscope came into being. It is well-nigh impossible to distinguish the nature of laterite, so far as its constituent minerals are concerned, from descriptions such as this.

Coupled with Buchanan's description, the references indicate that, although it "contains a very large quantity of iron in the form of red and yellow ochres" these constituents, hydrous oxides of iron, cannot be regarded as the principal constituents of laterite. It can even be argued that the essential constituent was some mineral other than ochre, for it would seem that Buchanan regarded the laterite as a mineral, that is, a substance which is homogeneous.

After travelling northwards along the western coast of the peninsula as far as Karwar, with deviations inland at several places, Buchanan turned away from the ocean and ascended the Ghats to the plains of southern Bombay Presidency and western Mysore State. He then travelled southwards more or less parallel to the scarp of the Ghats and then turned in a north-easterly direction, along the valley of the Tunga River, through Shimoga. All along this route he reported the presence of laterite until he reached a point a little west of Shimoga.

Near Gati, Buchanan recorded:

"... a hill producing iron ore, which is wrought to some extent. It is found in veins intermixed with *Laterite*, like the ore of *Angada-puram* (Angrypar) in *Malabar*. The ore is of the same nature with what is usually smelted in the peninsula; that is to say, it is a black sand ore ..."

In all, there are nearly 20 entries concerning laterite or brickstone, most of them being merely a record of the occurrence of laterite at the locality referred to. In one of his last entries concerning laterite Buchanan merely refers to it as brickstone. In a later book concerning Bihar he refers to it merely as brickstone also, so that it would appear that Buchanan did not have such a fancy for his brain-child as we have at the present day.

The first half of the 19th Century saw the gradual adoption of the term "laterite" by travellers, mostly geologists, more particularly in India and the near-by countries. Rocks having the same general characteristics as Buchanan's laterite were found scattered far and wide through India and Burma, and most of those who recorded the occurrence of laterite seemed to have considered it some form of ironstone, that is, an impure hydrous iron oxide rock. This is very understandable, for much of it had developed over highly ferruginous crystalline rocks and consequently this laterite contained more iron oxide minerals than the laterite formed over granites and similar rocks, as was that seen by Buchanan. It must be remembered always, that this was in the days before the development of the techniques now used for the study of rocks. Complete chemical analyses, or merely analyses for ten or a dozen constituents were not available. The petrological microscope had not been developed, and sure methods of mineral identification had not yet come to light, even for the study of comparatively simple crystalline rocks. Even today we have no sure method of determining the content of some rocks with respect of the more indefinite materials developed by weathering, such as for instance, amorphous hydrated aluminium and iron oxides, secondary silica and the like: approximations are all that can be obtained at best, even employing a whole battery of techniques such as chemical analysis, the petrological microscope, differential or simple thermal analysis, X-ray diffraction, and so on. In those days reliance had to be placed on comparatively simple tests of a discriminatory nature only, as I have just outlined.

Knowledge concerning the nature of the laterite seen by Buchanan came slowly. Southern Malabar was examined by Philip Lake whose findings were published in 1890. This geologist could distinguish three distinct types of laterite. Firstly, the "plateau laterite" which caps the hill tops as a kind of "summit bed" so to speak, which Lake considered to have been formed *in situ* by the decomposition of the gneiss. A second type was what Lake termed "terrace laterite," to be found on the slopes below the "plateau laterite." The third type "valley laterite" occurred at still lower levels. It is the "summit bed" that Buchanan appears to have referred to most.

The latter half of the 19th Century saw the slow development of the present day techniques of examining and describing rocks. Chemical analysis was applied more and more, to ascertain the constituent elements of rocks and their relative proportions. Following Sorby's work of the 1850's the petrological microscope was developed and used to ascertain in what way those elements were combined, that is, the mineral expression of the chemical composition. Not only this but the mutual relationships of the different minerals were also studied. Rock textures were found to have a definite meaning in many instances, and a large body of knowledge gradually accumulated.

Naturally, sooner or later, someone was bound to apply these new techniques to the study of laterite. To Max Bauer, of the University of Marburg, who had been examining European bauxites late in the 19th Century, goes the credit of first publishing work of this nature dealing with tropical laterite. He microscopically examined specimens of laterite and associated crystalline rocks from Mahé, one of the Seychelle Islands, in conjunction with chemical analyses by Busz. The chemical analyses showed the highly aluminous nature of the laterite, which Bauer attributed to the presence in quantity of the hydrated aluminium oxide gibbsite, to be seen in the thin sections. Further, he showed the close relationship there existed between the laterite and the underlying crystalline rocks, not only chemically as to constituent elements, but also with regard to micro-structure. Particularly was this so in the instance of the laterite found over the diorite, for he found that this laterite retained in itself the structure of the diorite: the laths of feldspar seen in the diorite were represented by colourless rectangular areas of gibbsite and the ferromagnesian mineral by limonite-bearing areas. The lime and magnesia of the diorite had disappeared from the laterite, as also the silica. The laterite over the granite had quartz grains of similar size and shape to those of the granite and Bauer could recognise the granitic structure retained in the laterite. Standing alone, the evidence concerning the laterite over the granite could be heavily discounted, for the holocrystalline allotriomorphic equigranular structure of granite is not particularly distinctive when retained in weathered products, in contradistinction to the structure of some basic igneous rocks, especially the ophitic texture of dolerites and closely related rocks, for these structures are often readily recognisable even when the rocks are completely altered by weathering.

However, the evidence was such that the conclusion was inevitable: the laterite of Mahé was formed *in situ* by the weathering of the granite and of the diorite, and, furthermore, those weathering processes had removed the combined silica, the lime and the magnesia, leaving the iron and aluminimum as hydrated oxides, and the quartz.

About this time, geologists of the Geological Survey of India had been paying some attention to the problem of the formation of laterite. The results of Max Bauer's work was considered to have settled the question as to the real nature of primary laterite, that is, laterite which has been produced directly by weathering processes acting upon parent materials, before any redistribution of the constituents has occured consequent upon the continued action of weathering processes involving the movement of ground water through the laterite mass.

The results of chemical analytical work by the Warth brothers were published soon after the turn of the century. Their work showed that the term laterite had been applied by geologists in India to a wide range of materials, so far as chemical—and therefore mineral—composition was concerned. On the one hand, highly aluminous varieties existed, rich in the hydrated aluminium oxide mineral gibbsite and containing little limonite; on the other hand, highly ferruginous rocks, almost free of alumina, were also termed laterite, rocks consisting mainly of limonite, principally goethite; and there were all manner of varieties between these two extremes.

These last, rich in limonite, to which Buchanan would have applied the term "brown hematites," were considered best designated "iron ore," so, towards the close of the first decade of this century some authors considered the term "laterite" to be of more value as a rock name if it were restricted to mean those more highly aluminous rock types which lie in composition between iron ore on the one hand and the aluminium ore bauxite on the other.

Thus, when a chemical analysis of such a material showed an alumina figure above 52 per cent. and less than 5 per cent. iron and a very low silica figure it was considered to be bauxite. On the other hand, if the ferric oxide figure rose to something over 40 per cent. or so it was considered to be iron ore. In between lay laterite.

This view was by no means universally accepted, as is shown by the letters to the Editor of the *Geological Magazine* in 1910.

Even to this day we find those who advocate strongly the restriction of the term laterite to materials such as those just described: it is the concept widely held by geologists and mining engineers and is implicit in most of the papers read at a symposium dealing with the "Problems of Clay and Laterite Genesis" at the Annual Meeting of the American Institute of Mining and Metallurgical Engineers at St. Louis, Missouri, early in 1951. The one who used the term in a manner differing from this concept was a soil worker, G. D. Sherman.

Among soil workers there is a division of opinion. There are those who follow Pendleton's concept that laterite is "an illuvial horizon, largely of iron oxides, with a slag-like cellular or pistolitic structure, and of such a degree of hardness that it may be quarried out and used for building construction." Apart from the insertion of the concept of origin embodied in the term "illuvial" there is little if any difference between Pendleton's application of the term and that of the geologists of the Indian Geological Survey before the turn of the century and before anything like a thorough knowledge of these materials was obtained by the application of the techniques of rock examination now in use.

The inclusion of a concept of origin in a definition of a rock is considered, by the present speaker and many others, to be fundamentally erroneous: it requires one to secure satisfactory evidence of origin where often it is not possible to do so and to decide which of several modes of origin fit the known data. Further, one can never be sure that one has all the possible information which can enable one to make a valid decision as to origin, one which cannot be negated by subsequent work. In most instances the origin of a rock is a philosophical concept only, and is derived from observable and measurable data. It cannot be sufficiently emphasized that only observable and measurable features should be taken into account when naming a rock. It is possible, in some instances, for the same minerals to be assembled in the same proportions by a variety of methods. This applies generally and not only to laterite and similar products of weathering; it applies to granite, for example. Not infrequently there is some structure present which suggests a particular origin for a rock under discussion but this is not always so, by any means. Furthermore, it is possible for different workers to consider the same rock to have different origins, as indeed is the case with laterite; it would be particularly unfortunate if each worker used a different name for the same rock, just because each considered it to have a different origin.

Fox, in 1936, sought to clarify the position by examining some of the laterite to be found in Malabar and Canara provinces along the south western coast of the Indian peninsula. Unfortunately, it would appear that a thorough examination of all the different types of laterite occurrences was not undertaken, especially of that occurring on the summits of the hills, to which Buchanan referred so often and which Lake called "plateau laterite" some ninety years later. Whereas the exposure at Tellicherry examined by Fox can be interpreted simply as a mass of very impure iron oxide, the other occurrence, of which analyses are given of the profile exposed in the quarries at Cheruvannur, can be regarded as a profile in which there was a certain amount of enrichment by hydrated oxides of both iron and aluminium in the upper portions. From the illustration, this occurrence is down the slope a little distance below the hill-top and may correspond to Lake's "terrace laterite."

Those portions of western Mysore, where Buchanan reported laterite as being abundant, appear to have been entirely overlooked in discussions as to the true nature of laterite.

Amongst the laterite near Shimoga, at Kemmangundi, not far from the route followed by Buchanan, there is some laterite reported by A. M. Sen to have composition as set out in Table I.

Table I

Laterite from Kemmangundi

Al_2O_3	62.50	42.90	41.72
Fe_2O_3	5.10	25.40	30.27
SiO_2	0.36	10.40	2.97
H_2O	31.90	20.70	22.64
CaO			0.56
MgO			0.03
TiO_2			tr.

Parent rock:—Diorite or Hornblende diabase

For the best part of a century the term *laterite* was applied to a wide range of rocks ranging in composition from an impure iron ore containing a large amount of limonite, to a somewhat ferruginous bauxite. The question arises whether the term is best applied in the restricted sense that Pendleton so vigorously advocates, namely an "illuvial horizon" in which the cementing material is largely iron oxide, for which the term *ferricrete*, proposed by Lamplugh in 1897 is very suitable, or whether it should be applied in the sense that it should lie in composition between iron ore, on the one hand and bauxite, the ore of aluminium, on the other.

The difficulties of ascertaining always whether an occurrence is indeed illuvial, or what its origin really is, are manifest. It is not sufficient to assume that it is always of the same origin: indeed, there is much to suggest the contrary.

To the speaker, the restricted sense, developed by geologists early this century, appeals as being the more useful. It is a concept which depends solely upon characteristics of mineral composition and of field occurrence as broad sheets, characteristics which can be determined approximately by carefully planned chemical analysis and by field observations of the extent of an occurrence. It is considered that no concept of origin should be involved in the name given to any rock, be it granite, basalt, sandstone or even laterite. This is not to say that the origin may not be indicated by a suitable adjectival qualifier preceding the name.

The term *latosol*, recently introduced by C. E. Kellogg, offers a solution to one of the problems of the nomenclature of these materials. While he cannot find himself at one with Kellogg in the use of the term *laterite* to include sesquioxide-rich materials in which hydrated aluminium oxides are low or virtually absent, the present speaker considers the introduction of such closely defined terms to be long overdue in pedological science and has little doubt but that further similarly closely defined terms will be introduced in the course of time, to cover adequately the different varieties of these very interesting materials.

For the present purposes, the speaker will use the term laterite to include those consolidated, non-friable materials consisting essentially of hydrated oxides of both iron and aluminium, lying in composition between ironstone or iron ore on the one hand and the aluminium ore bauxite on the other. Where quartz, or any other mineral, becomes at all prominent in the constitution of the rock, say over ten per cent, the term is suitably modified adjectivally.

One must apply very carefully the various definitions depending upon ratios of alumina to silica, either of the rock as a whole or of the "clay fraction" only—this being selected by some because it is considered that this fraction would contain little or no free silica, such as quartz, but would be truly representative of the argillaceous material and therefore of the material produced by chemical alteration during weathering. It must always be borne in mind that these are merely short-cuts used to minimise the work involved in securing knowledge, sufficient for the work in hand, of the chemical constitution and therefore of the mineral constitution of the rocks or soils under investigation.

South-Western Australia

Let us now turn to this south-western corner of the Australian continent.

The features to be observed within 200 miles of Perth conform to the general pattern of the whole of the area and will be referred to principally.

First it is desirable briefly to outline the physiography and geology of the area.

Physiographically one of the most outstanding features is the Darling Scarp, which forms the western edge of the Great Western Plateau. Here, along a line sub-parallel to the coast, and about 20 miles or so inland, the land surface drops from altitudes of 800 to 900 feet above sea level to the coastal plains standing less than 100ft. above sea level for the most part, rising to higher altitudes only in the belt of coastal limestone hills, which rarely rise to an altitude greater than 200ft.

The Great Western Plateau can be regarded as having several elements.

One, the Darling Peneplain, is a general level of flat-topped hills and ridges or divides between fairly broad valley systems, the tops of the ridges standing at some 900 to 1,000ft. above sea-level.

Rising above this peneplain are a number of higher, comparatively isolated hills such as Needling Hills and Mount Bakewell, remnants of an older land surface, the roots of earlier divides between broad valley systems which collectively form the Darling Peneplain.

Cutting down into this Old Plateau or Darling Peneplain is a system of valleys with gentle slopes and broad salt river flats, standing at an altitude of some 600 ft. or so above the present sea-level. These broad valleys with their salt flats are remnants of an old drainage system which appears to have flowed in a general direction from North to South. The various branches of the Mortlock River and the extensive salt river flats to be seen between Kellerberrin and Merredin afford good examples of this system. In this region, the valley systems are very broad and only small remnants of the old Darling Peneplain remain. The lower reaches of these river systems are characterised by the much narrower, steep-sided valleys of young rivers.

These various elements are not seen clearly near Perth but are best seen if one goes up onto the higher places east of the Avon River or southwards beyond the Beaufort River.

The rocks of the western portion of the Great Western Plateau consist mainly of granitic gneisses and granites, granulites, metasedimentary schists—some of which are sillimanite- and andalusite-bearing-quartzites and slates. Cutting these are dykes of dolerite and epidiorite. To the east of the North Branch of the Mortlock River and of the Avon River at York and along the Albany Highway from 120 miles or so from Perth onwards and extending eastwards, the wheat belt has occurrences of moderately well lithified conglomerate, argillaceous grits and sandstones—some of which show horizontal bedding—and very sandy clays. These sediments lie upon the undulating eroded surface of the crystalline rocks, and are comparatively young, judging by their lithification, which is comparable with rocks of the Plantagenet beds and are believed to be of terrestrial origin. Gritty sediments underly much of the high level sand-plain country of the north-eastern and eastern wheat belt, the sandy soils of the elevated sand-plains being residual soils derived from these gritty sediments.

To the west of the Darling Scarp the comparatively low-lying coastal plains consist of a narrow belt of sandy limestone and sand hills, in part of aeolian origin, with a broad belt of lenticular beds of very sandy clays and argillaceous sands. These yield loamy sands and sands at the surface. In places there are patches of fresh-water limestone. These sediments rest upon a thick series of calcareous shales with inter-bedded coarse grits and shales below, these grits being the aquifers of the artesian basin around Perth. Laterite does not occur west of the vicinity of the Darling Scarp.

The Darling Peneplain is characterised by the presence of a group of ferruginous and aluminous rocks and gravels which form a sheet or cuirass upon the old rocks beneath. As exposed at the surface these materials are of two kinds. The fairly hard stone is popularly referred to as *ironstone* or *conglomerate* while the *gravel* consists of an unconsolidated mixture of ferruginous nodules with some quartz sand and clay. The more firmly lithified materials are commonly medium- to dark-brown, sometimes quite light-brown. In most places they consist of nodules set in a matrix of fine grained material, the so-called "concretionary" laterite, much of which is better referred to as *laterite with concretions*. In places the laterite consists almost entirely of more or less spherical pellets around about 5 to 10 mm. across, firmly joined at their points of contact: this form appears to be confined to channels through the less porous rock, these channels having developed along joints inclined at any angle. They constitute zones of free passage to lower levels for rainwater falling on the surface above or higher up the slope. This is a purely concretionary laterite commonly styled "pisolitic laterite" on account of the size and shape of its constituent nodules resembling those of peas. Another less common form is the so-called vesicular type which consists of massive material through which irregularly shaped anastomosing channels pass: this type not uncommonly has a splotchy appearance in light and dark browns, though fair uniformity of a dark brown is quite common. Rarely, one finds a massive form of laterite, free from nodules except near the surface: in places it may be quite porous, but on the whole is fairly massive and dense. Whatever the type of laterite, some form of nodular structure is generally present somewhere in any exposure of laterite and this nodular structure has come to be regarded, by some, as the distinguishing characteristic of laterite, so much so, that when they see a light or dark brown or reddish brown nodular material occurring as an extensive layer they immediately identify it as laterite. It is intended to return to a consideration of this nodular structure later and to show that the vesicular, nodular and pisolitic types are derived from the dense, massive variety by the continued action of waters passing through the laterite to lower levels. Before doing so, however, it is first desirable to give some attention to certain features of the laterite and of the materials closely associated with it.

Firstly, concerning the composition. A number of analyses of laterite occurring in and near the Darling Range have been published and a few of these will suffice to indicate the general nature of this rock (see Table II).

Table II

Laterites from the Darling Range

		Wongan Hills	Gooseberry Hill	Parkerville	Ridge Hill
SiO_2	....	5·96	6·41	15·83	10·30
Al_2O_3	....	44·66	36·74	31·68	22·53
Fe_2O_3	....	19·08	39·80	24·95	48·56
FeO	....	....	....	2·52	....
MnO	....	....	0·06	...	0·05
MgO	....	tr.	0·15	0·62	....
CaO	....	tr.	0·10	0·01	....
Na_2O	....	....	....	0·14	....
K_2O	....	....	. ..	nil	....
H_2O-	....	0·58	1·20	2·69	} 15·82
H_2O+	....	26·44	13·73	19·55*	
TiO_2	....	3·10	1·98	2·07	3·24
SO_3	....	0·18	....	....	....
P_2O_5	....	tr.	tr.	0·09	....
Cr_2O_3	....	....	0·03	....	....
V_2O_5	....	....	0·23	....	....
		100·00	100·43	100·15	100·50
Combined SiO_2	....	....	1·97	10·17	4·94
Analyst	....	E.S.S.	E.S.S.	S.E.T. D.B.	R.T.P.
Date	....	1901	1912	1947	1946

* By ignition loss

These analyses show the laterite to consist mainly of hydrated oxides of iron and of aluminium, together with some hydrous silicate of aluminium, some free silica and a little oxide of titanium. The most probable mineral expression of this chemical composition is a rock consisting mainly of gibbsite and limonite with some kaolin or halloysite and quartz and a little doelterite or leucoxene or possibly traces of residual ilmenite.

Much of the limonite is probably goethite, but the presence of some lepidocrocite and maghemite is suggested by the magnetic properties of nodules derived from laterite. Some nodules collected at Kalamunda, for example were quite strongly magnetic as collected but rapidly lost their magnetic response when heated to 800°C in a neutral atmosphere. This suggests the presence in the nodules of the magnetic anhydrous iron oxide mineral maghemite, which in turn is derived from lepidocrocite by dehydration. A number of years ago, Professor R. T. Prider drew attention to the polar magnetic properties of laterite at Wattle Flat.

It will be noted that the soda and potash, the lime and magnesia, to be found in abundance in the underlying rocks, are almost completely absent from the laterite. The Darling Range laterite manifestly conforms to the concept of laterite in the restricted sense of a material somewhere between a bauxite on the one hand and iron ore on the other; most of the occurrences, so far examined chemically, are somewhat impure from the admixture of quartz and clay.

There are certain features of the field occurrence to which I would direct your attention.

Firstly, beneath the laterite there is commonly a zone of partially or completely bleached clay. Simpson, in 1912, referred to the laterite as an efflorescence which drew ferric oxide and alumina from the rocks below, resulting in a layer from which most and often practically the whole of the ferric oxide has disappeared, leaving this stratum of white or pale-coloured clay.

In 1915 Walther visited this State and described the occurrence of laterite here. Figure 1 is a diagrammatic profile after that author. It shows the massive cuirass or crust of laterite overlying a mottled horizon which in turn overlies a bleached horizon which in its turn passes into the rock beneath.

This sequence has come to be regarded as the normal sequence of horizons of laterite-bearing profiles when truncated. It is postulated that above the hard laterite crust there existed incoherent, leached, sandy soils which have been eroded away from those areas in which laterite or lateritic gravels are exposed.

In evidence of this, pale yellowish grey loamy sandy soils exist which have a brown, obviously ferruginous horizon some eighteen inches to three feet or so beneath. In places, local erosion has removed the overlying loamy sands and exposed the gravelly horizon and this gravelly horizon has much the same appearance as the gravel associated with the solid rock laterite elsewhere. These gravelly horizons are regarded by many as the same as the more massive occurrences of laterite. It is proposed to show that they differ materially and so cannot be regarded as the same as the aluminium oxide-bearing laterite of the Darling Range, for instance.

Walther's diagram may be taken to represent closely the features to be observed in an occurrence of laterite at Parkerville. At that place, where some quarrying has been done in the past to secure material for roads and where a Roads Board Hall and tennis courts are now situated, there is exposed a section of massive laterite developed *in situ* from a quartz dolerite dyke.

minerals of the parent rock are now a mixture of dark brown limonite with a small proportion of ironstained, presumably colourless mineral, possibly a mixture of gibbsite and clay minerals. A little quartz is scattered through the section.

When the chemical composition of the laterite close to the boulder is compared with that of the quartz dolerite from which it was formed, it may be observed that the ratio of ferric oxide to alumina of the laterite is what it should be if there has been no movement of the iron with respect to the alumina. If most

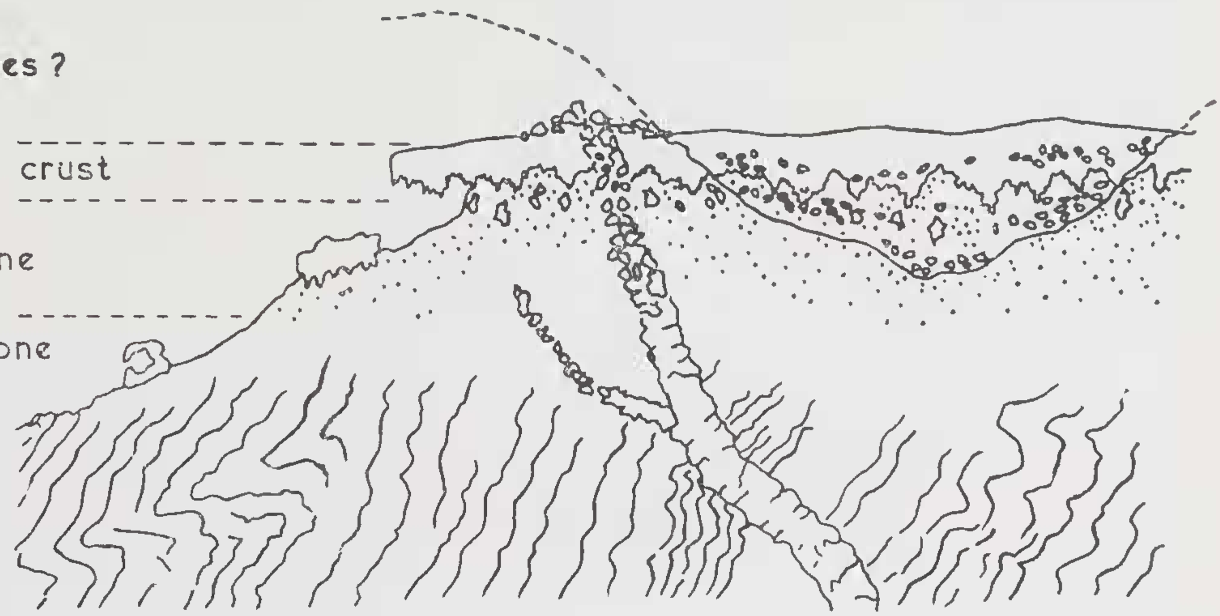

Fig. 1.

This section has much to offer in enlightment as to the nature of laterite in the Darling Range and the sequence of events in connection with it.

First, there is a layer of laterite, much thicker in proportion than the layer figured in Walther's diagram: the topmost 18 inches or so is gravelly, but below this the laterite is massive. Immediately below the laterite there is a mottled red and pale greenish blue clay and lower still a pure white koalinic clay.

The laterite has the typical composition of rocks of this group, using the term in the retricted sense of a rock lying in composition between an iron ore on the one hand and an aluminium ore on the other. The analysis of the rock has been published in the Society's *Journal* recently.

In the laterite there is evidence of the typical spheroidal weathering of basic crystalline rocks of igneous origin. Also there is immersed in its substance a small boulder of quartz dolerite and near its base, a very large boulder which projects down into the mottled clay horizon and around which is a downward extension of the laterite from the layer above. These boulders have the appearance of being cores of spheroidally weathered blocks of dolerite, the original joint faces of which are still discernable.

Not only are the weathering cracks of the parent rock preserved but in parts the microstructure is preserved also. In thin section the original feldspar laths are now represented by elongated rectangular patches of gibbsite, while the areas occupied by the ferromagnesian

of the ferrous iron of the dolerite—all but the amount shown to be present in the laterite—is considered as having been converted to ferric oxide, then the ratio of ferric oxide to alumina remains virtually undisturbed.

The combination of these three features of preservation, firstly, the preservation of the structure produced by spheroidal weathering, secondly the preservation of evidence of poikilitic structure and thirdly the retention, undisturbed of the iron to alumina ratio, is considered to be sufficient evidence that this laterite has been formed *in situ*, not by deposition from solutions which have brought in the constituents from some place else, be it from some hypothetical horizon directly above, or from higher up the slopes of the hill, but that the laterite has been formed by the removal, in solution in circulating ground waters, of practically the whole of the soda and potash, the lime and magnesia and a large proportion of the combined silica.

The nodular structure in the top portion of the laterite and the gravelly soil above it, are considered to have developed by the continuing action of weathering, probably under different climatic conditions.

There is no reason to believe that the laterite formed from the granite originated in any way differing from the manner in which the laterite was formed from the quartz dolerite, for the junction of the laterite formed from the quartz dolerite with that of the laterite alongside it, formed from the granite, can be traced.

Nor is the laterite at Parkerville the only occurrence where the structure of the parent rock is preserved.

In an old cutting north of the present railway line at Mt. Helena there is a vertical section showing laterite derived from a basic dyke rock preserving perfectly the structure of the original rock, and in which the spheroidal weathering cracks of the original basic dyke can be detected. Further, one can run a knife down the junction between the laterite from the basic dyke rock and that formed from the granitic country rock

Another occurrence of laterite which preserves the structure of the parent basic dyke rock has been found on the Beaufort Downs property: this farm is on the road from the Martup Hills on the Albany Highway to Woodanilling further east. This occurrence is nearly 150 miles away, to the south of those first mentioned.

Emphasis on basic dykes as being rocks which yield laterite in which the structure is well preserved is unfortunate but inescapable. The basic dyke rock possesses a structure which, when preserved in its weathering products, is very readily recognisable and clearly demonstrable to others, while granitic rocks do not possess such a clearly defined structure. It is true that one can consider certain features to be seen in thin sections of some massive laterite specimens to be relicts of the structure of the parent granite, but the evidence is not so clear and is open to doubt.

Once the validity is admitted of the conclusion that the laterite is primarily formed in place from the basic dyke rock by the ground waters removing the alkalis and alkali earths and much of the combined silica, and not by the deposition of the laterite constituents from solutions brought to the place from elsewhere, certain other deductions must necessarily follow. The mottled clay and the pure white, bleached kaolin strata below are quite devoid of any evidence of the structure of the parent rock and further, the regeneration of such a structure from them does not seem possible. Consequently, they cannot be considered to be intermediate stages in the formation of laterite from the parent basic dyke rock.

It is concluded therefore, that the clays were formed neither before the formation of the laterite, nor at the same time, but subsequently thereto, as weathering of the parent rock continued and still continues beneath the protective mantle of laterite.

There is some reason for the belief also that underneath the laterite mantle the conditions are even yet those which led to the formation of a bleached clay, for, at the present day, the granite appears to be still weathering to a bleached, quartzose kaolin underneath the laterite crust. Only where they are exposed directly to the weathering agents or beneath a thin pervious soil layer do the granites or greenstones show evidence of weathering to red or brown iron-bearing clays or loamy soils.

The laterite was formed at some early stage in the development of the present land surface.

Firstly, an undulating surface, in places hilly along divides between broad valley systems, was produced by the erosion of granites, gneisses, metasediments and other crystalline rocks.

More or less argillaceous grits, coarse and fine sandstones—in places showing horizontal bedding—with local conglomerate, were laid down upon the eroded surface, in great measure filling the valleys. The thickness of these sediments is not known but appears to have been considerable for they reach high up the sides of the highest hills where they occur.

Following the deposition of the gritty sediments erosion developed very broad valley systems virtually plains, with isolated hills standing higher, the remnants of the divides between the valleys which constituted the broad plain country. This plain country is the Darling Peneplain.

Following the development of the Darling Peneplain lateritisation occurred during a definite climatic phase. A change in climate followed with the consequent change of final product of weathering of the feldspars and ferromagnesian minerals. Instead of the aluminium-bearing minerals having the whole of their combined silica removed, leaving the hydrated aluminium oxide gibbsite, they had only some two thirds removed, leaving hydrous aluminium silicates, chiefly kaolin.

Local conditions have caused variations in the nature and intensity of colouring of the horizons beneath the laterite, because of varying proportions and state of oxidation of the iron left along with the kaolin.

After the period of laterite development which could well have occurred on a low-lying plain as Woolnough has postulated, elevation has caused a rejuvenation of erosion in the then existing drainage pattern. This gave rise to broad valleys in which extensive, very sandy, mostly unstratified terrestrial sediments were deposited. These sandy sediments blocked the drainage system and have given rise to the widespread elevated sand-plains of our wheat belt and South West.

Following this terrestrial sedimentation, rejuvenation of erosion has occurred in at least two stages. At first the streams cut down to a level about 200-300 feet below the laterite-covered plateau. A major uplift of at least 600 feet then followed and the rejuvenation of erosion has caused the lower reaches of the rivers to cut downwards, while at the same time, the upper reaches continued to extend and are still extending their valleys laterally, so that in many places there is only a line of laterite-covered, flat-topped hills to mark the divides between broad valley systems the lower parts of which consist of flat, marshy or salt river flat country standing about 600 ft. above sea level, Woolnough's 600 feet level. Indeed, in many places the whole of the laterite and underlying clays have now been removed exposing bare granite and gneissic hills, the so-called "Rocks," which are the very roots of the divides between these post-peneplanation mature valleys or of the monadnocks which stood above the peneplain.

Certain features of the landscape and associated soils call for attention at this stage.

First, attention is drawn to figure 2a which shows diagrammatically a section of a side of a valley in granitic country. On the left there is the flat-topped ridge or divide between adjacent valleys. It is laterite covered, the laterite being a residual eluvial horizon which has been further altered as to structure and composition by the continuance of weathering action. The soil cover is thin or absent: in places loose boulders of laterite occur. Such soil as there may be is full of ironstone nodules and is mainly grey sand with a little clay and organic matter. As one progresses down the slope, light brownish or greyish sandy loams derived successively from the mottled or coloured clay horizon and the pallid or bleached clay horizon appear. The valley may not penetrate the pallid, often

laterite and the formation of gravelly soils from the post-laterite yellow sandstones where the gravel and gravel-stone, at first sight, resembles nodular or concretionary laterite.

Figure 3 shows the low wall of a small gravel pit in sandstone country that occurs some 120 miles or so from Perth along the Albany Highway. It shows a yellow argillaceous sandstone which has developed vertical cracks down which iron-bearing solutions have penetrated. These solutions have impregnated the walls of the cracks with reddish hydrous iron oxide. Near the top of the sandstone, a little below the sandy gravel, the columns of sandstone have cracked horizontally with consequent penetration of iron-bearing solutions which have followed the easier courses along the cracks. The isolated fragments thus become impregnated by hydrous iron oxide from all sides and the outer

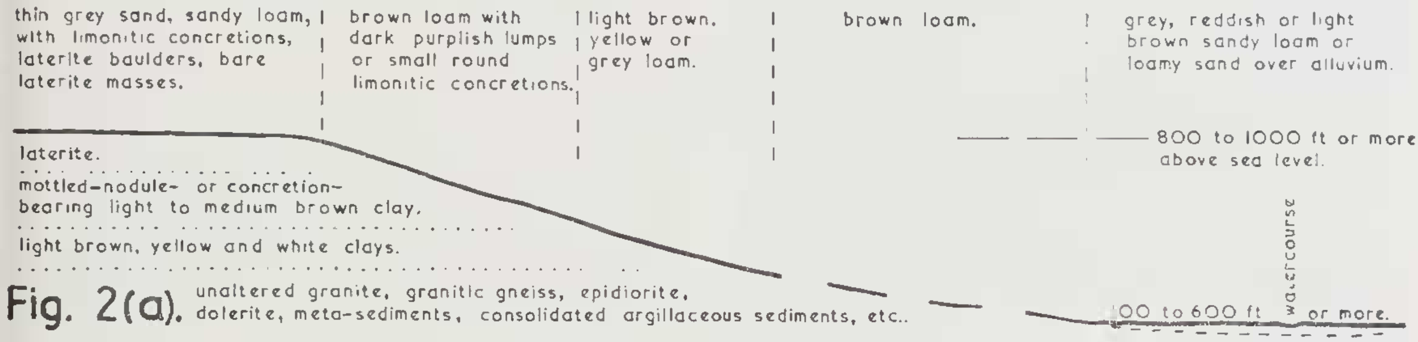

Fig. 2(a).

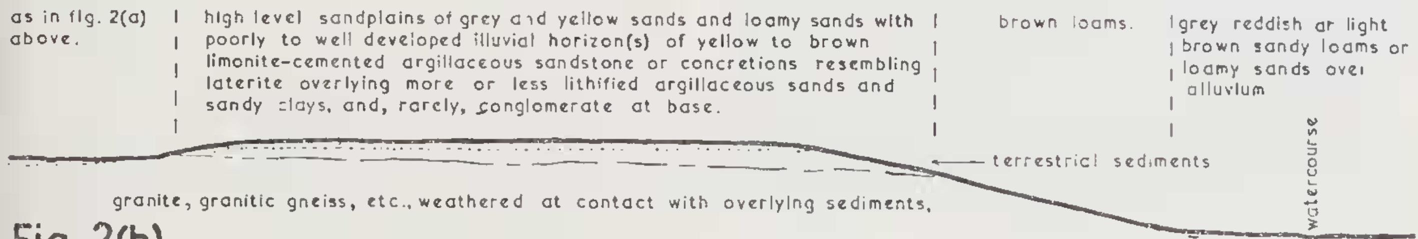

Fig. 2(b).

bleached horizon, but, should it do so, red and brown sandy loams have developed, formed by the weathering of the granitic rocks exposed to the climatic conditions and physiographic circumstances of the very recent past and present.

Where the argillaceous grits and sandstones and very sandy clays form sandplains, the diagram becomes slightly different, as shown in figure 2b.

On the left is a slope such as shown in figure 2a. In the middle is a very sandy flat-topped ridge of gritty sediments which have shared in the mottling and bleaching which followed lateritisation: the residual soils derived from the grits are the very pale yellowish grey slightly loamy sands, which constitute our high level sand plains. On the right the valley slopes down to the zone where residual reddish brown sandy loams occur, similar to those of the valley bottom of figure 2a.

Before closing, it is desirable that some reference be made to the further weathering of

portions are constantly being removed. Such fragments also crack across and become several fragments, all being separated by the rootlets and by loamy sand washed in between them by moving water on its way down to the zone of permanent saturation. Thus are formed "disintegration" type residual nodules.

In places the sandstone does not wholly disintegrate into separate nodules, but on the contrary, irregular more or less vertical "solution channels" develop, leaving an almost nodular mass between with channels filled with loose, grey sand. This "nodular" mass is easily broken to loose sandy gravel.

A similar process of disintegration occurs in laterite, yielding loose ironstone nodules in a very sandy matrix.

Other forms of nodular or concretionary structure have been developed in both the laterite and in the argillaceous grits and sandstone.

In places a spotty type of mottling develops a little below the surface, where isolated spots become enriched with limonite to such an extent that eventually they may consist largely of limonite. Such pellets yield a "residual" type of nodule which may be anything from a very dense almost black and pure limonite to a lump of dark purplish red to brownish black, friable material with a thin, dense, comparatively hard smooth surface, very similar to the "disintegration" type of nodule and apparently indistinguishable from them. In sandy loam soils derived from sandstones such nodules may be very numerous forming a principal constituent of a lower horizon in the soil profile. These nodules have a similar origin to that of similar nodules formed in laterite, being deposited in the matrix from solutions and often are very similar in appearance. This has led many to consider an horizon rich in such nodules a laterite horizon: it is considered, however, that such nodules should be styled "laterite" only if they consist largely of hydrated aluminium oxide minerals rather than the hydrated silicates as well as hydrated iron oxide minerals. The few such occurrences examined by the present speaker appear to have an origin differing entirely from that of the laterite itself, being the same as the origin of nodules formed in the laterite matrix by the continuance of weathering action upon the primary laterite, which is itself a residual skeleton derived from the parent rock by removal of the alkalis, alkali earths and combined silica in solution. In the one instance, the ferruginous nodules have developed in argillaceous sandstone; in the other, they have developed in laterite subsequent to the formation of the laterite; this nodular structure is not a distinguishing characteristic of laterite, although most laterite has developed this structure.

FIG. 3.

The development of such nodular structures can occur during weathering in any sufficiently porous rock or material, laterite included, provided sparingly soluble matter be present and that climatic and topographic conditions are suitable. The development of nodular structures occurs in a wide variety of materials and is merely indicative of the similarity in response of the various rocks to the same forces of weathering as expressed in similar climates acting in similar topographic situations with like drainage patterns. Different types of nodules are formed depending upon whether a disintegrative or accretionary action is involved and this, in turn, depends upon the whole of the environment in all its complexity.

Before closing, I wish to express my thanks to the Director of the Government Chemical Laboratories, Mr. H. P. Rowledge, for his kind permission to use the facilities of the Mineral Division outside office hours in order to carry out certain phases of this investigation, which is still in progress. My thanks are also due to Miss Ethel Curran, late of Perth Modern School, for the basic translation of the Latin of Wallerius, and to Mr. and Mrs. Mira Liber for their valued help in the translation from the German of various articles such as those of Johannes Walther and Max Bauer. Lastly, I thank you for your kind attention to-night.